From grassland to farm to lawn: Estimating the environmental consequences of historical and contemporary land management practices in the U.S. Great Plains

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In the last 150 years, the Great Plains region of the United States has become a major center of agricultural production, and the landscape of the region has changed accordingly. The first half of the period, roughly from 1870 to 1940, witnessed the settlement of the area by Euro-American farmers and the conversion of native grassland to cropland, extending from the eastern Plains to the western Plains. The second half of the period, roughly from 1940 to the present, was a time of intensification of farming, when production increased dramatically through the use of new inputs, such as synthetic fertilizer, irrigation, and high-yielding crop varieties. At the same time, the amount of land in farms and the number of people on farms contracted and non-agricultural settlements grew, particularly in and near such urban centers as Denver. These three phenomena, the expansion of cropping between 1870 and 1940, the intensification of agriculture from 1940 to the present, and the simultaneous growth of cities and suburbs, have had important consequences for the environment of the Great Plains and of the world through the greenhouse gas (GHG) fluxes they have engendered. This paper focuses on the most recent period, quantifying the GHG emissions associated with the soil system. In particular, it examines the effects of population growth and distribution on the environment since 1940 by evaluating the impact of lawn conversion and maintenance on the soil GHG budget of the Great Plains.

Background and Literature

Though lawns have long been part of residential landscapes, the quantity of lawn in the Great Plains and in the U.S. as a whole dramatically increased in the second half of the twentieth century with the spread of suburbanization. As the density of housing decreased, the amount of lawns surrounding houses increased, and the proportion of housing lots planted in lawn also seems to be increasing over time (Robbins and Birkenholtz 2003). In the early 1990s, it was estimated that more U.S. land was in lawns than in in irrigated corn, the predominant irrigated crop (Milesi et al. 2005). As lawn expanded across the U.S., it also underwent a qualitative shift, with management intensifying and inputs of fertilizers and pesticides exceeding those used in agriculture (Robbins and Birkenholtz 2003). The conversion of agricultural land to lawn is, therefore, “a process where one produced nature, that of high-input agriculture, is replaced by another, that of high-input lawns” (Robbins and Birkenholtz 2003: 181).

Much of the ecological literature about lawns focuses on the daunting task of estimating just how much lawn there is, either in particular areas or in the U.S. as a whole. The U.S. Census of Agriculture tracks the amount of land going into and coming out of farms, but does not indicate what happens to land after it goes out of agriculture; more detailed datasets and databases, such as the U.S.D.A. National Resources Inventory and the U.S. Geological Survey’s Land Use and Land Cover dataset, are too recent to allow for analysis of the full time period over which suburbanization has occurred (Theobald 2001). Because lawn is usually grown in small patches surrounding homes, it cannot readily be identified with moderate resolution satellite data, though for urban areas it can be estimated based on the amount of impervious land cover appearing in satellite images (Milesi et al. 2005). Aerial photography at the scale required to measure lawn coverage is quite expensive, but has been used in small quantities to calibrate a model that estimates lawn extent as a function of tax data in Franklin County, Ohio for one point in time (Robbins and Birkenholtz 2003). A more promising approach for estimation of land in lawns over the second half of the twentieth century is a database constructed by Theobald (2001) that classifies Census blocks into four categories of housing density (urban, suburban, exurban, and rural) at each decade from 1950 to 2000. This dataset has been used for studying changes in land use (see, for example, Brown et al. [2005]), but is not publicly available.

Previous studies of the biogeochemical dynamics of lawn have concentrated on lawn as such, without examining the process of converting from some other land use into lawn, and without comparing the GHG consequences of lawn to those that would prevail under an alternative land use. Using the Biome-BGC ecosystems process model, Milesi et al. (2005) find that lawns represent a net carbon sink, sequestering it in the lawn system, though this sink is somewhat offset by lawn maintenance activities, such as fertilizer application, irrigation, mowing, and the use of pesticides and herbicides.

The Region and the Data

The Great Plains region encompasses 476 counties in 12 states: Colorado, Iowa, Kansas, Minnesota, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming. These counties stretch from the 32nd parallel in the south to the Canadian border in the north. All have annual precipitation of less than 700 millimeters and are below 5,000 feet of elevation. They share a common semi-arid climate, but there is substantial subregional variation, with temperatures rising from north to south, precipitation declining from east to west, and native vegetation varying from shortgrass steppe in the west to tallgrass prairie in the east (Hartman et al. 2011).

Large-scale Euro-American settlement of the Great Plains began as a result of the 1862 Homestead Act, which distributed 160-acre parcels of land to those willing to farm them. The eastern part of the Plains, having more precipitation and therefore being more conducive to agriculture, was settled and cropped first. In the western Plains, where precipitation was scarcer, settlement occurred later, and livestock husbandry preceded cropping (Gutmann, Deane, and Witkowski 2011). Cropping in the western Great Plains was never as extensive as in the eastern Plains, and focused on more drought-resistant crops, such as wheat and sorghum, while corn was more prevalent in the east (Cunfer 2005). This process of settlement and agricultural conversion was documented as it occurred by the U.S. Censuses of Population and Agriculture, and the data produced by those censuses are now available in machine-readable format (Gutmann 2005a,b).

The Census of Agriculture lists the number of acres devoted to each crop and inventories each type of livestock in each decade, but does not reveal the environmental consequences of crop cultivation and livestock raising. And while the Census of Population records the number of people and housing units in each county, it does not indicate the extent of lawns surrounding those housing units or the greenhouse gas flux produced by the installation and management of those lawns. To answer questions about the environmental impacts of the conversion of native grassland to agriculture and agriculture to urban and suburban settlements, we therefore combine historical population and agriculture data with biogeochemical simulation using the Daycent model to estimate soil GHG fluxes over time and cumulatively.

Methods

The Daycent model is a generalized ecosystem model that simulates the nutrient dynamics of various types of land use and land cover, and has successfully been used to simulate agricultural systems in the U.S. Great Plains (Hartman et al. 2011). For this project, Daycent simulations were run for each county over the period from 1860 to 2003. The model takes as input a schedule of daily agricultural events for each major crop rotation, daily historical weather data, and soil data. Its outputs include system carbon levels (C), N_2O flux, and CH_4 absorption, from which we calculate net GHG budgets for the soil system in each county as the interannual change in system C, plus N_2O emitted, less CH_4 absorbed . The model ignores emissions from farm equipment, the fossil-fuel burning required to synthesize fertilizer, and the CH_4 generated by livestock. We have estimated these factors separately elsewhere, but here focus only on the soil system, examining how soil GHG budgets change when we consider the conversion of cropland or native grassland to suburban lawns between 1940 and 2000.

Each Daycent model run simulates the biogeochemical dynamics associated with a schedule of daily agricultural activities (referred to here as the "schedule file"), carried out in the context of known soil qualities and weather patterns. For 21 representative counties, a set of schedule files was created on the basis of historical data and documents (described in Parton et al. [2005]), including as many schedules as are required to adequately represent all of the major dry and irrigated crop rotations, as well as land that was never cropped (pasture) and retired cropland (return). Each schedule file covers the entire period from 1860 to 2003; within each schedule, crop rotations change over time as indicated by the historical record. For example, one schedule file for Baca, Colorado represents native range in the years prior to 1895, wild hay from 1895 to 1921, a dryland fallow/winter wheat/sorghum rotation from 1921 to 1956, an irrigated corn/sorghum/hay rotation from 1956 to 1976, and an irrigated corn/sorghum/hay/winter wheat rotation thereafter. The set of schedule files for Weld, Colorado is illustrated in Figure 1. In addition to specifying the crops grown in each year, the schedule file indicates dates of planting, cultivating, and harvesting, as well as dates and amounts of fertilizer application and irrigation.

The remaining 455 counties were clustered around the 21 representative counties on the basis of similarities in climate and agricultural history, and the schedule files for the representative counties were used to simulate cropping in each county in the cluster, along with soil and weather data specific to each county. For this paper, results are presented at the cluster level by weighting results for each schedule file according to the amount of land in each crop in each cluster, and the proportion of the cluster represented by each county within it. For example, Douglas, Colorado is part of the cluster represented by Baca, Colorado. Soil dynamics in Douglas were simulated by running the Daycent model with the schedule files for Baca and the soil and weather data for Douglas, and results were then weighted by the proportion of land in each crop rotation in the whole Baca cluster and by the proportion of that cluster represented by Douglas. All land still in crops as of the 2007 Census of Agriculture was placed in one of the cropping schedules; land that had been cropped previously but removed from production before 1987 was placed in a schedule file representing land retired from cropping ("return"); land that had been cropped previously but removed from production between 1987 and 2007 was placed in a schedule file representing the Conservation Reserve Program; and land never cropped was placed in a pasture file.

Lawns are simply another crop, so additional schedule files were created to represent the conversion of land to lawns in each of the representative counties. Twelve files were created in all for each representative county, simulating land being converted to lawn at six intervals (1945, 1955, 1965, 1975, 1985, and 1995) and coming from either pasture or dryland cropping. The lawn schedules for Weld are illustrated in Figure 2. After presenting Daycent results for cumulative GHG flux from 1940 to 2000 in the absence of lawns, we examine the soil dynamics associated with the establishment and maintenance of lawn by presenting a time series of system carbon flux, soil N_2O emissions, and CH_4 uptake by the soil resulting from lawn conversion for one square meter of land in two of the representative Great Plains counties.

We then examine the impact of lawn conversion in the region as a whole by scaling up the Daycent results and aggregating by clusters. By definition, land that was converted to lawn must have never been cropped or must have been retired from cropping. Adding lawns to the GHG budgets at the cluster and region level therefore requires re-assigning land from the pasture and return schedules to the lawn schedules. This re-assignment depends on how much land went into lawns in each decade between 1940 and 2000 and on how much of that land had previously been in native grass (in which case it would come from the pasture schedule) and how much had been in crops (in which case it would come from the return schedule). Neither the amount of land in lawns nor its previous use is known empirically. For this simulation, we assume that the amount of land in lawns is proportional to the number of new housing units created in each decade. We model all conversion between 1940 and 1950 as if it had occurred in 1945, all conversion between 1950 and 1960 as if it had occurred in 1955, and so on through 1995. For a minimum estimate, we model one acre of lawn per new housing unit and for a maximum estimate we model two acres of lawn per new housing unit.

The previous use of the land planted in lawn makes a difference in terms of greenhouse gas impact, as we will demonstrate in the first section of the results. As will be explained below, lawn conversion would have had the largest impact on the overall GHG budget of the Great Plains if all lawn had come from pasture and the smallest impact on the overall GHG budget of the Great Plains if all lawn had come from retired cropland. However, it is not possible that all lawns could have come from retired cropland because there was simply not enough cropland retired. We therefore estimate the maximal impact on the GHG budget of the Great Plains by assuming that all of the lawns came from pasture and estimate the minimal impact by assuming that as much of the lawns as possible came from retired cropland, with the remaining lawn coming from pasture. After we present the maximum and minimum estimates of the greenhouse gas impact of lawn conversion for the region as a whole and for each county cluster, we look more closely at two of the clusters that experienced the most growth in housing between 1940 and

2000 to examine the spatial unevenness of lawn conversion and its environmental consequences within the Great Plains.

Results

Figure 3 maps the cumulative GHG fluxes associated with the soil system (cropping and pasture) from 1940 through 2000 resulting from the Daycent simulation prior to the addition of lawns. GHG fluxes are negative where greenhouse gases are being sequestered in the soil and positive where they are being released into the atmosphere. In general they are positive in the dryland cropping clusters and the clusters where additional land was plowed for cropping after 1940, and negative in clusters with more irrigated cropping and where more land was retired from cropping after 1940 (Hartman et al. 2011).

Lawn Results by Square Meter

Turning to lawn simulations, Figures 4 through 7 illustrate the results of Daycent model runs for the conversion of pasture to lawn and dry cropland to lawn in two Great Plains counties, Hamilton, Nebraska and Weld, Colorado, at the level of the square meter. These counties have been chosen because they represent the climatological variation of the Great Plains, with Hamilton in the east receiving much more rainfall than Weld in the west.

Pasture to Lawn. In figures 4 and 5, the black line represents the soil dynamics associated native grassland or pasture, and the colored lines represent the conversion of pasture to lawn at each point in time. Native grasses are taller in the east than in the west, and therefore store more carbon in the soil. These differences can be observed in the higher level of carbon in the pasture system in Hamilton relative to Weld, as illustrated by Figures 4a and 5a. As a result of differences in rainfall and native vegetation, the biogeochemical consequences of lawn conversion also differ between the eastern and western Great Plains. Conversion of pasture land to lawn requires the plowup of native grasses, resulting in the release of carbon from the soil and the system. Figure 4a demonstrates that this loss of soil is dramatic and ongoing in Hamilton, and that in the absence of this plowup, the pasture system would otherwise have absorbed carbon over the simulation period, producing a net negative GHG flux. In contrast, Figure 5a demonstrates that in Weld, much less carbon is released as a result of lawn conversion, and that the system begins to absorb carbon only a few years after plowout, achieving levels higher than would otherwise occur if the land remained in pasture.

Figures 4b-c and 5b-c show much more consistent results for the two counties. In both Hamilton and Weld, lawns release more N_2O and absorb less CH_4 than do native grasses. Figure 4d demonstrates that, in Hamilton, the conversion of pasture land to lawn always results in an initial spike in GHG emissions. Though these emissions begin to decline shortly after plowout, they remain at higher levels than would be produced were the land to remain in native grass. Figure 5d demonstrates very similar results for Weld, though GHG emissions decline much more rapidly there, and in some years are less than the GHG emissions that would be produced by native grass.

Dry Cropland to Lawn. In figures 6 and 7, the black line represents the soil dynamics associated with cropping until 1964 in Hamilton and 1974 in Weld, with the land remaining idle thereafter; the colored lines represent cropping until the year indicated, followed by a direct conversion to lawn. Though the graphs begin in 1940, the simulation that produces them involves cropping beginning in 1885 with a corn/winter wheat rotation in Hamilton and cropping beginning in 1920 with a fallow/winter wheat rotation in Weld. Figures 6a and 7a indicate that, as a result of the longer and more intensive cropping in Hamilton, the level of carbon in the cropping system in Hamilton in 1940 is roughly the same as that in Weld in 1940, despite having begun at higher levels in Hamilton, as illustrated in Figures 4a and 5a. These figures also show that the abandonment of cropping (black line) results in a much more rapid restoration of carbon to the system in Hamilton than in Weld, a result of the earlier retirement of cropland along with higher levels of rainfall and higher levels of plant production in the native grass in Hamilton. Both figures also demonstrate that the conversion of dry cropland to irrigated lawn restores carbon to the system much more rapidly than does leaving the land idle. However, Figure 6a shows for Hamilton a slight release of carbon during the years in which lawn is planted, which does not occur in Weld in Figure 7a.

Figures 6b and 7b demonstrate that lawn produces more N_2O than does dryland cropping, a result of the higher levels of synthetic fertilizer used in the lawn system, along with the irrigation. They also demonstrate that soil N_2O emissions fall nearly to zero when cropland is retired if the land is not converted to lawn. Similarly, Figures 6c and 7c show that the lawn system absorbs less CH_4 than does either active or retired dry cropland. Figure 7d demonstrates that, in Hamilton, the initial conversion of pasture to lawn results in a brief spike in GHG production, followed by a period of GHG sequestration. Over time, however, GHG sequestration decreases and turns into GHG release as a result of ongoing N_2O emissions and the saturation of the soil with carbon. In Weld, the initial conversion of dry cropland to lawn results in immediate GHG sequestration, but over time this sequestration diminishes and turns to GHG release, as in Hamilton.

Cumulative GHG Comparison. Figure 8 illustrates the difference in cumulative GHG emissions from 1940 to 2000 associated with the conversion of one square meter of dry cropland or pasture to lawn in Hamilton and Weld. Figures 8a and 8b demonstrate that the conversion of pasture to lawn always results in an increase in cumulative GHG emissions. These emissions are higher in Hamilton than in Weld, and are higher the earlier the conversion occurs in both counties. Figure 8c demonstrates that, by 2000, the cumulative GHG emissions associated with lawn are always higher than those associated with retired cropland in Hamilton. In Weld, however, the cumulative GHG emissions associated with lawn conversion are always lower than those associated with retired cropland. In both counties, the earlier the conversion from cropland to lawn, the lower the cumulative GHG emissions.

Lawn Results Scaled to Clusters and Region

The per-square-meter results demonstrate that the overall impact of lawn conversion on the GHG budgets of the region and county clusters within the region will depend on the amount of land converted, the distribution of lawn conversion over time, the spatial pattern of lawn conversion across the Great Plains, and the prior history of the land. They also demonstrate, however, that if amount, chronological distribution, and spatial distribution of conversion are held constant, GHG emissions will be increased the most if all lawn comes from pasture and GHG emissions will be increased the least, or possibly decreased, if all lawn comes from retired cropland. In order to estimate the GHG impact of lawn conversion on the Great Plains as a whole, we derive the spatial and chronological distribution of conversion from the intercensal increase in housing units at each decade from 1940 to 2000, and assume that each new housing unit was associated with the conversion of either one or two acres of land to lawn. To calculate maximal GHG impact, we assume that all lawn comes from pasture, and to calculate minimal GHG impact, we assume that all lawn comes from retired cropland. If the amount of lawn exceeds the amount of retired cropland, we assume that the excess comes from pasture.

Great Plains. Figure 9a graphs cumulative GHG for the Great Plains region as a whole over the period from 1940 to 2000 for each of five scenarios: no lawn, one acre of lawn per housing unit with all land coming from pasture, one acre of lawn per housing unit with all land coming from dry cropland, two acres of lawn per housing unit with all land coming from pasture, and two acres of lawn per housing unit with all land coming from dry cropland. Figure 9b is an inset showing the period from 1975 to 2000 on a larger scale. This graph demonstrates very little change resulting from the conversion of dry cropland to lawn: when we assume that each new housing unit is associated with one acre of lawn, the total cumulative GHG emissions for the Great Plains increases by only 0.58%; when we assume that each housing unit involves 2 acres of lawn, GHG emissions increase by 5.28%. This large difference between the one and two acre scenarios is likely a result of insufficient retired cropland to produce two acres of lawn per new housing unit, requiring some conversion of pasture to lawn. If all lawn comes from pasture, cumulative GHG emissions during this period are increased much more dramatically, by 14.54% with one acre per housing unit and 29.09% with two acres per housing unit.

County Clusters. Just as population growth was not evenly distributed throughout the Great Plains between 1940 and 2000, neither was lawn conversion. Figure 10 maps new housing units built during this period by cluster, and also shows metropolitan areas by population size. Figure 11 illustrates the chronological distribution of new house building by cluster. In general, the Colorado clusters gained the most new housing units, though the Kingsbury, South Dakota cluster also saw a large increase. Figures 12 and 13 map the percent change in cumulative GHG emissions by cluster, assuming one acre of lawn per housing unit, for conversion from pasture and conversion from dry cropland, respectively. Tables 1 and 2 provide the same information, but also include the percent change associated with the planting of two acres of lawn per new housing unit. These maps and tables demonstrate that lawns and their environmental impact are unevenly distributed throughout the Great Plains, with lawn conversion having the largest impact in the Baca, Colorado cluster and at the edges of the Plains.

Subcluster Analysis. Lawns and their environmental impact are also unevenly distributed within clusters. For example, though the Baca and Boulder clusters both saw large numbers of new housing units appear between 1940 and 2000, these units were disproportionately located in the western part of the Baca cluster – Crowley, Douglas, Elbert, El Paso, Kiowa, and Pueblo counties – and in the northern part of the Boulder cluster – Boulder and Jefferson counties. Figure 14 indicates these areas on the map and gives the results of separate analyses for the parts of these clusters with more and less new housing, under the assumption of one acre of lawn per new housing unit. These results indicate that lawn conversion in the western counties of the Baca cluster would have increased GHG emissions by nearly 50% if land was taken from pasture, but would have decreased GHG emissions by just over 2% if land was taken from crops. The impact would have been much less in the eastern counties of the Baca cluster, with conversion from pasture increasing the GHG emissions by 0.81% and conversion from dry cropland increasing GHG emissions by only 0.07%. In the Boulder cluster, conversion of pasture to lawn would have increased GHG emissions in the southern counties by 4.5%, but would have increased GHG emissions in the northern counties by 1561%. Had the lawns come from retired cropland, conversion would have increased GHG emissions by only 0.62% in the southern counties of the Boulder cluster, but by 1108% in the northern counties. This figure is so high because much more land was converted to lawn than was retired from cropping. Between 1940 and 2000, 306,940 new housing units were built in Boulder and Jefferson counties. We assume that this figure indicates 306,940 acres of lawn. However, only 111,577 acres of cropland were retired in these two counties, so even if all retired cropland were converted to lawn, the building of these housing units would have required the conversion of 195,363 acres of pasture to lawn, substantially increasing the GHG impact.

Discussion

The results of this simulation demonstrate that, through the conversion of land to lawns, population growth and the development of new housing in the Great Plains could have increased cumulative soil greenhouse gas emissions by up to 29% over the period from 1940 to 2000. The exact figure, however, depends on how much land was converted and on whether or not the land had previously been cropped. The second half of the twentieth century saw the contraction and intensification of cropping in the Great Plains. Little land was plowed for crops after 1940. Rather, marginal cropland was retired as farmers expanded livestock production and concentrated new inputs – such as fertilizer, irrigation, and higher-yielding crop varieties – on the land that remained in production (Hartman et al. 2011). Cumulative GHG fluxes from the soil system peaked in the early 1960s. Thereafter, crops and pasture represented a net GHG sink, though GHG emissions from other agricultural sources not addressed in this paper – notably livestock, farm equipment, and fertilizer synthesis – kept total agricultural GHG fluxes positive through most of the 20th century.

New housing and other urban and suburban growth during this period would have had to develop on land that either had never been plowed or had been retired from cropping. These prior land uses provided very different biogeochemical starting points. Native grassland or pasture would have been rich in soil carbon and, if left undisturbed, would have been more or less GHG-neutral over the long term, though may have produced positive fluxes in some years and negative fluxes in other years. The plowing of this land for lawns would have released substantial amounts of carbon, though in the drier west, the system would have rapidly recovered much of it, as a result of the irrigation and high levels of plant production associated with lawn relative to native grass. Nonetheless, the conversion of pasture to lawn anywhere in the Great Plains would have resulted in continually elevated levels of GHG emission. Land that had been retired from cropping, on the other hand, would have been depleted of carbon, and the planting of lawn would have restored that carbon more quickly than would have occurred had the land remained idle, though the initial planting may have disturbed the land in some parts of the Great Plains (as shown for Hamilton), resulting in a brief release of GHG prior to sequestration. Regardless of previous land use, lawns are heavily irrigated and fertilized, resulting in higher levels of soil N_2O emissions and lower levels of CH_4 absorption than would have occurred on either native grass or retired cropland. These components of the net GHG flux, however, are much smaller than the change in system carbon. The differential impact of lawn conversion produced by prior land use is most dramatically illustrated in the Curry, New Mexico cluster, where the conversion of one acre of land to lawns per housing unit would have increased GHG emissions by nearly 14% if the land had previously been in native grass but would have reduced GHG emissions by over 20% if the land had previously been cropped.

Our subdivided analysis of the Baca and Boulder clusters emphasizes the unevenness of lawn development in the Great Plains, and demonstrates that the environmental impact of lawn conversion is much more dramatic when analysis focuses on the localities where new housing was concentrated, rather than aggregating up to the region or even the county cluster. This analysis also pointed to the fact that suburban development did not necessarily occur in the same places where cropland was retired, and that the environmental impact of this development – simply in terms of soil GHG fluxes – would have been greater where native grassland had to be plowed to accommodate it.

Conclusion

This paper has argued that the planting of urban and suburban lawns on native grassland or retired cropland is an important part of the agricultural life cycle and contributes to our understanding of the environmental consequences of converting land to and from agriculture. It assessed only the greenhouse gas fluxes resulting from the simulated biogeochemical dynamics of grassland/pasture, cropping, and lawn management, leaving aside for the moment those resulting from farm equipment, irrigation, lawn mowing, fertilizer synthesis, and livestock raising. Adding these emissions will certainly change the picture. Moreover, future work might attempt to distinguish between residential and commercial lawns, as different management styles would produce different biogeochemical effects (Milesi et al. 2005). This paper demonstrated that lawn establishment and maintenance is more likely to increase the soil greenhouse gas budget in the eastern part of the Great Plains and where native grassland is plowed to accommodate lawn, and is less likely to increase the soil greenhouse gas budget – or may even reduce it – in the western part of the Great Plains and where lawn is planted on retired cropland.

Our estimate of the impact of lawns on the greenhouse gas budget of the Great Plains between 1940 and 2000 still presents a wide range. In order to produce a more precise estimate, our future work will seek a more accurate scaling unit between new housing and land in lawns, as well as a way to determine the prior use of land planted in lawn.

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Figures

Figure 1. Weld, CO schedule files

Year	Pasture	Return	CRP	Hay	Corn1	Corn2	Corn3	Dry1	Dry2	Irrig1	Irrig2	Irrig3
pre-1895	native range	native range	native range	native range	native range	native range	native range	native range	native range	native range	native range	native range
1895				wild hay/ graze	fallow-ww-corn					irr corn-potato-beet-oat-alf		
1910								fallow-ww-ww				
1920		fallow-ww-ww	fallow-ww-ww						fallow-ww-ww			
1923						fallow-ww-corn					irr corn-potato-beet-oat-alf	
1925							fallow-ww-corn					irr corn-potato-beet-alf
1931								fallow-ww				
1932		fallow-ww	fallow-ww						fallow-ww			
1945												
1950												
1951				hay/ graze								
1955												
1965												
1971											irr corn-beet-alf	
1973												irr corn-beet-alf
1974		return								irr corn-beet-alf		
1975												
1985												
1987			crp									
1995												

Figure 2. Weld, CO lawn schedules

Year	Return	DryLawn	DryLawn	DryLawn	DryLawn	DryLawn	DryLawn	Pasture	PasLawn	PasLawn	PasLawn	PasLawn	PasLawn	PasLawn
pre-1895	native range	native range	native range	native range	native range	native range	native range	native range	native range	native range	native range	native range	native range	native range
1895														
1910														
1920	fallow-ww-ww	fallow-ww-ww	fallow-ww-ww	fallow-ww-ww	fallow-ww-ww	fallow-ww-ww	fallow-ww-ww							
1923														
1925														
1931														
1932	fallow-ww	fallow-ww	fallow-ww	fallow-ww	fallow-ww	fallow-ww	fallow-ww							
1945		lawn							lawn					
1950														
1951														
1955			lawn							lawn				
1965				lawn							lawn			
1971														
1973														
1974	return													
1975					lawn							lawn		
1985						lawn							lawn	
1987														
1995							lawn							lawn

Figure 3. Cumulative GHG from the soil system (crops and pasture) in the U.S. Great Plains, 1940-2000

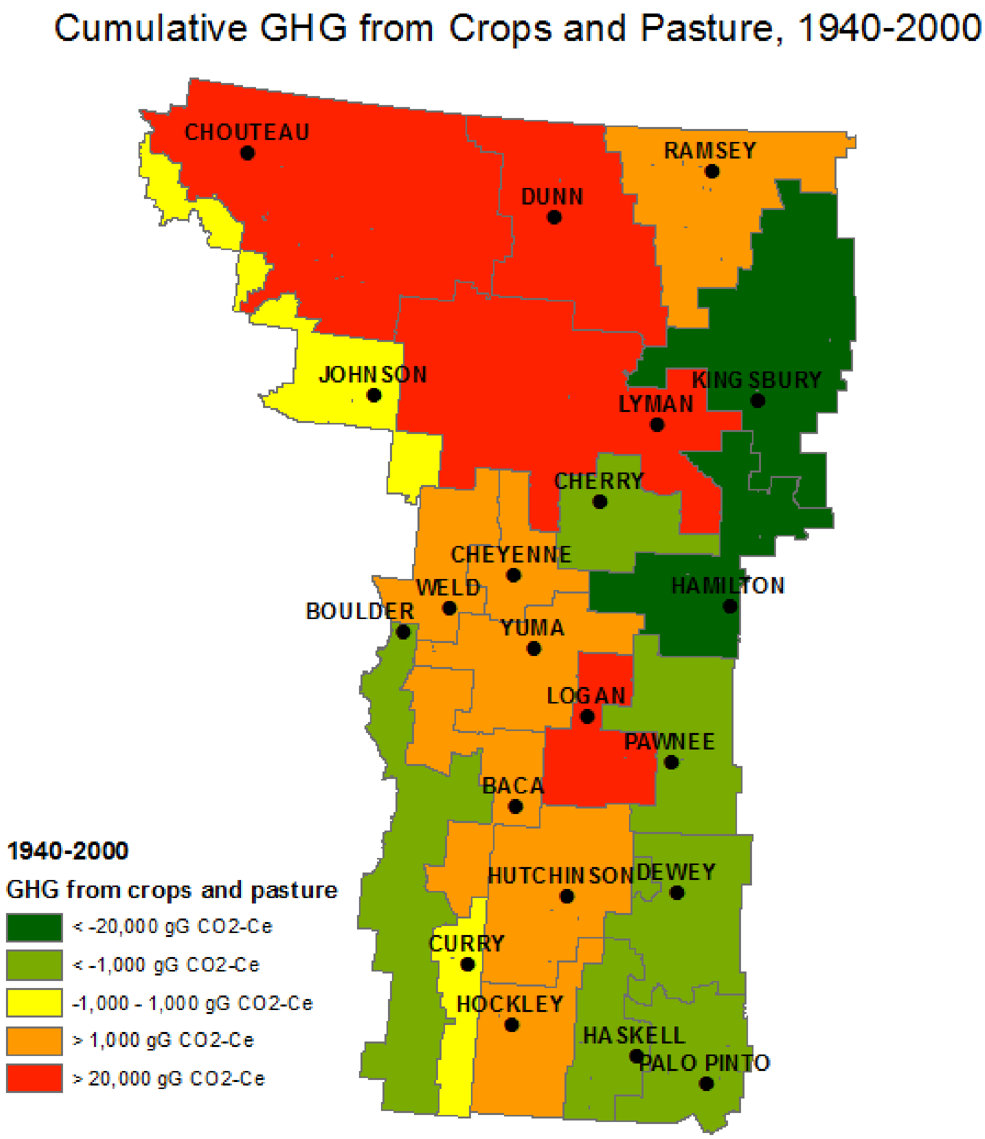
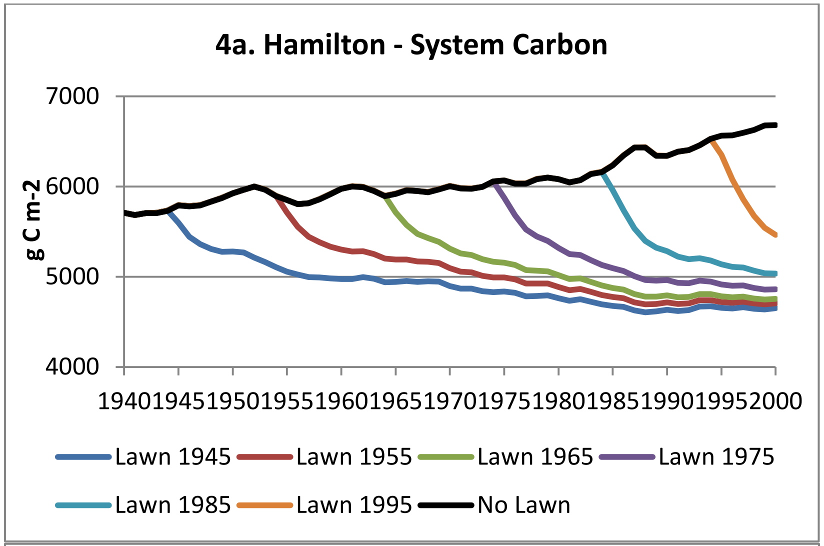
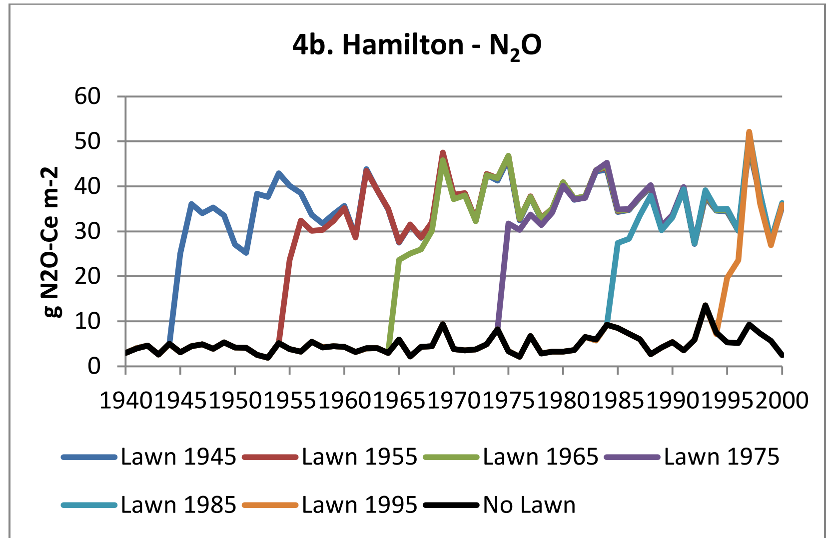
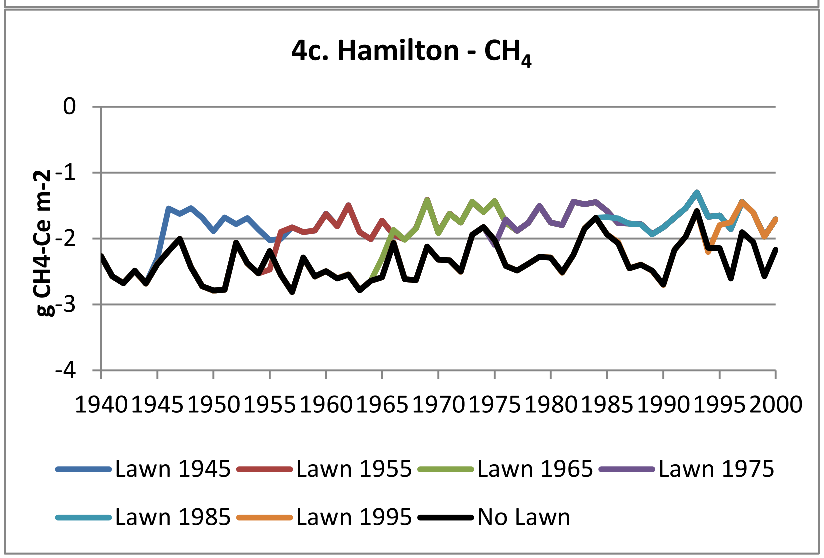


Figure 4. Pasture to lawn in Hamilton, Nebraska







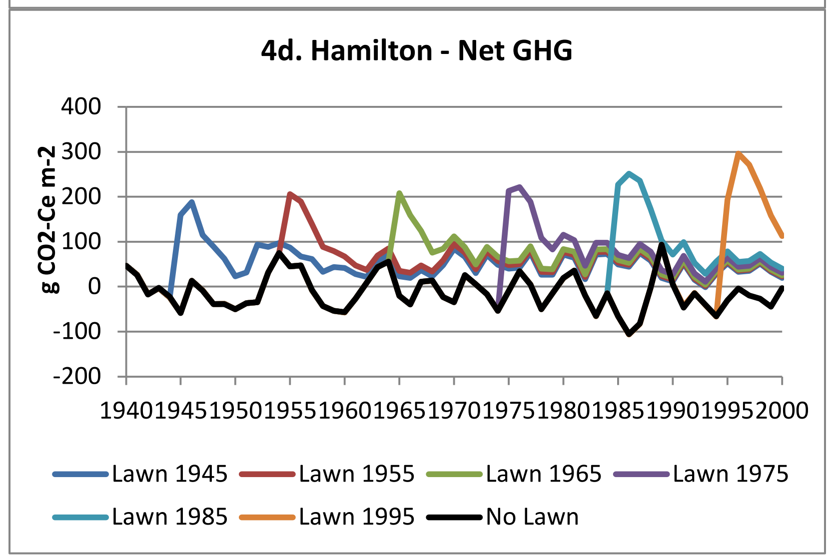


Figure 5. Pasture to lawn in Weld, Colorado

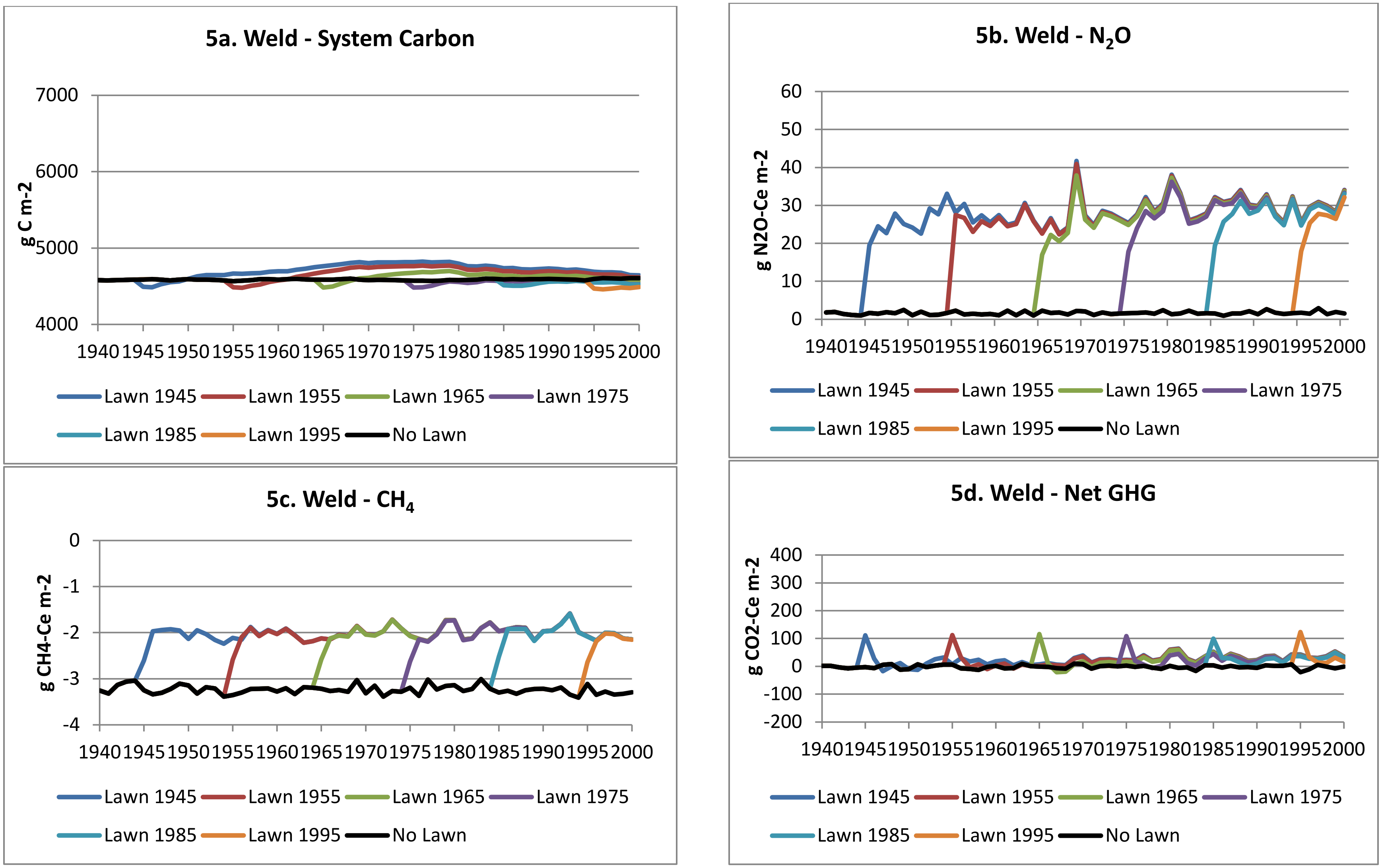


Figure 6. Dryland to lawn in Hamilton, Nebraska

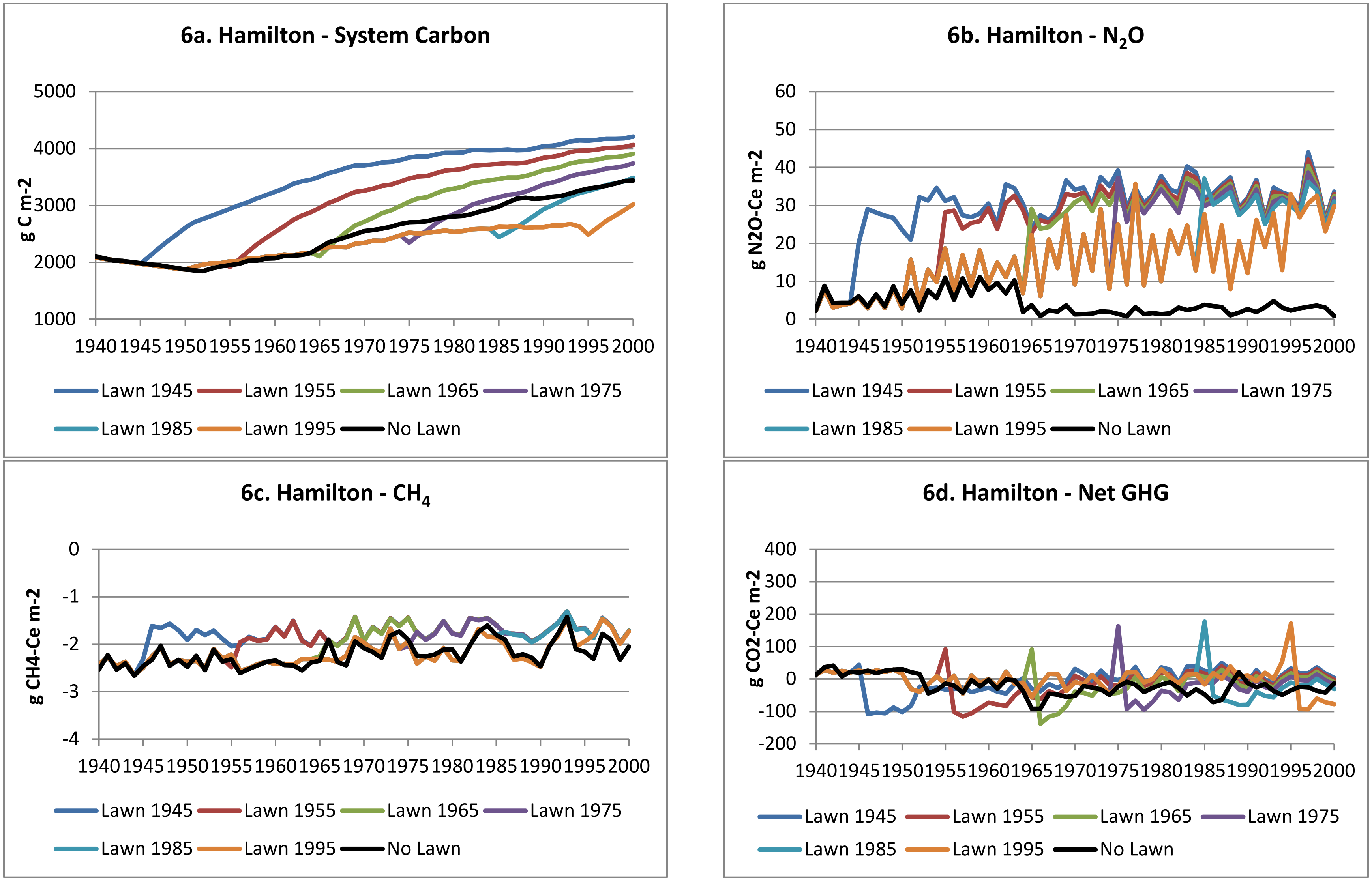


Figure 7. Dryland to lawn in Weld, Colorado

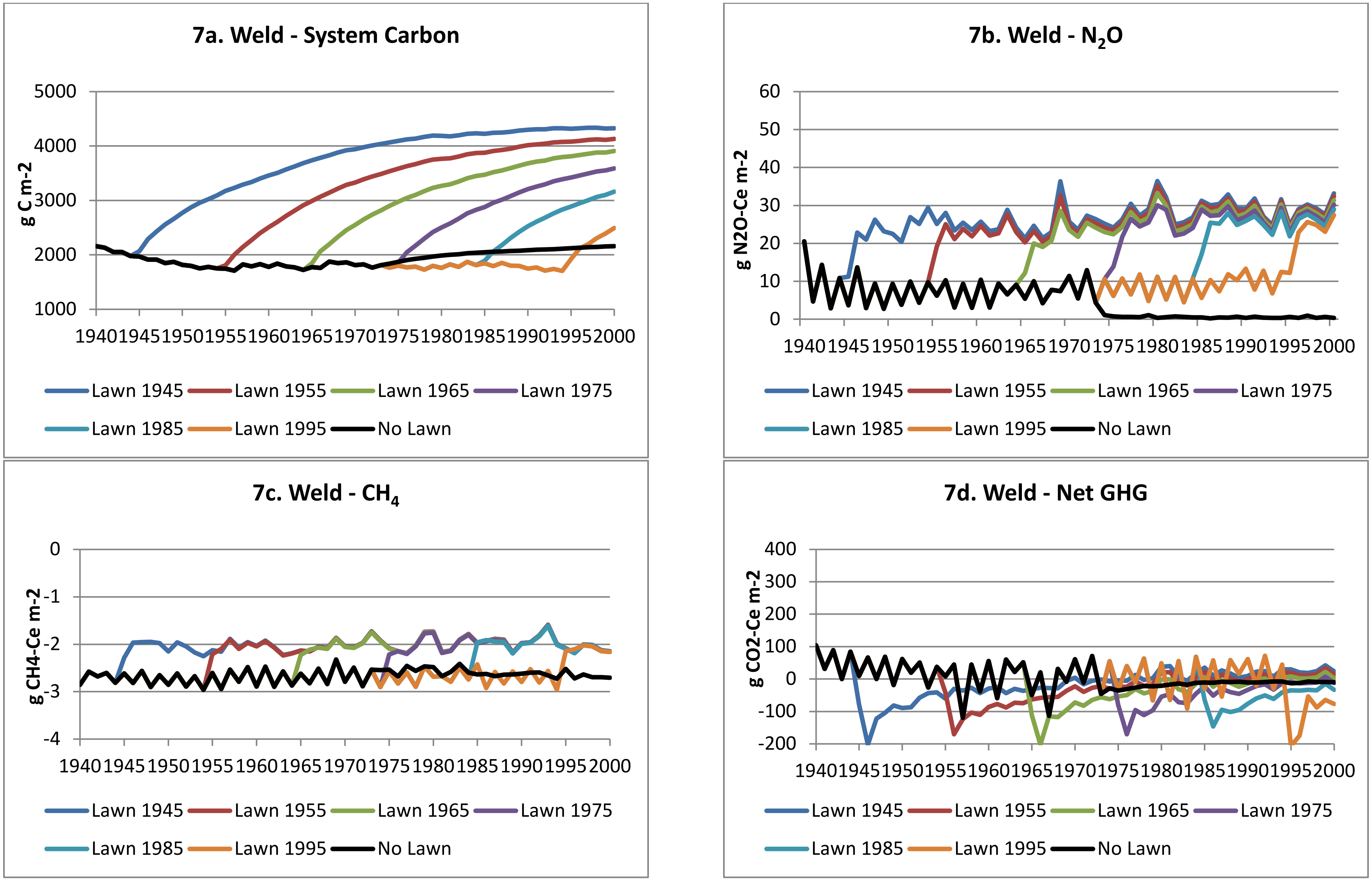


Figure 8. Cumulative greenhouse gas comparison

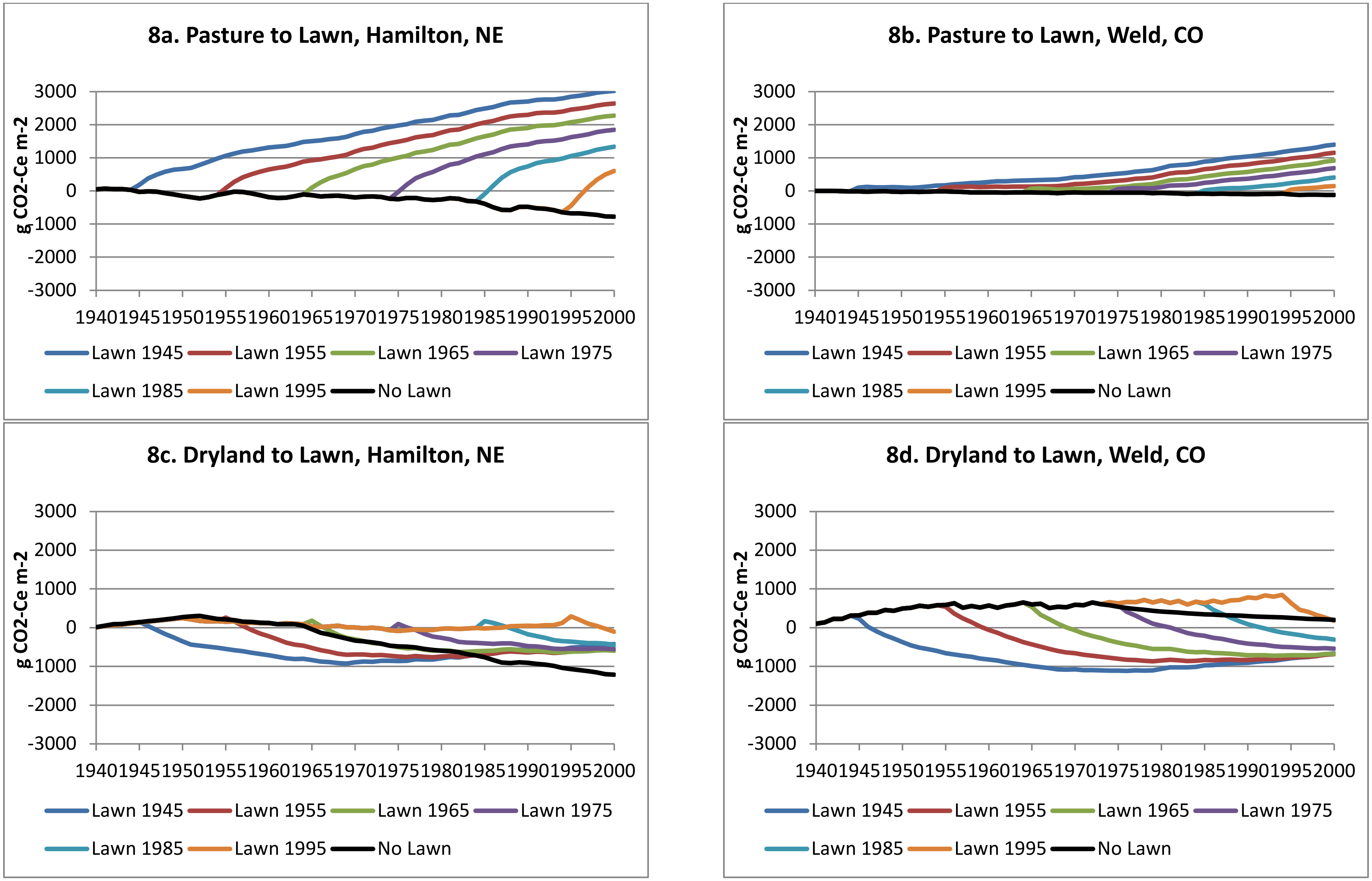
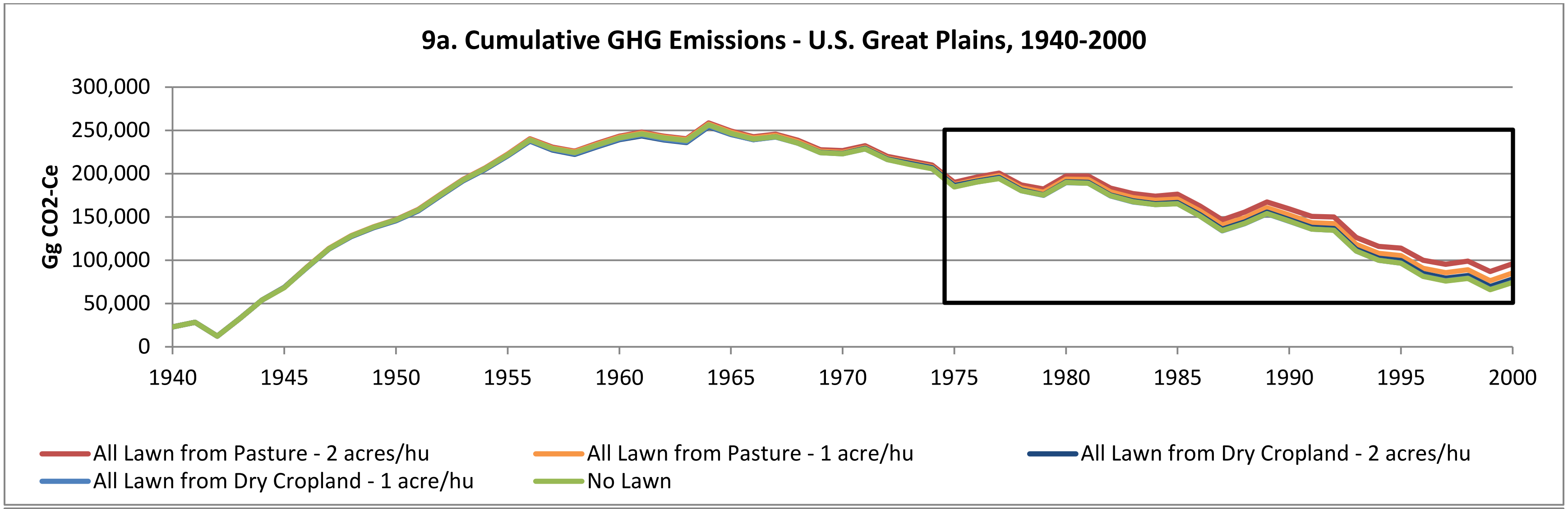


Figure 9. Change in greenhouse gas emissions



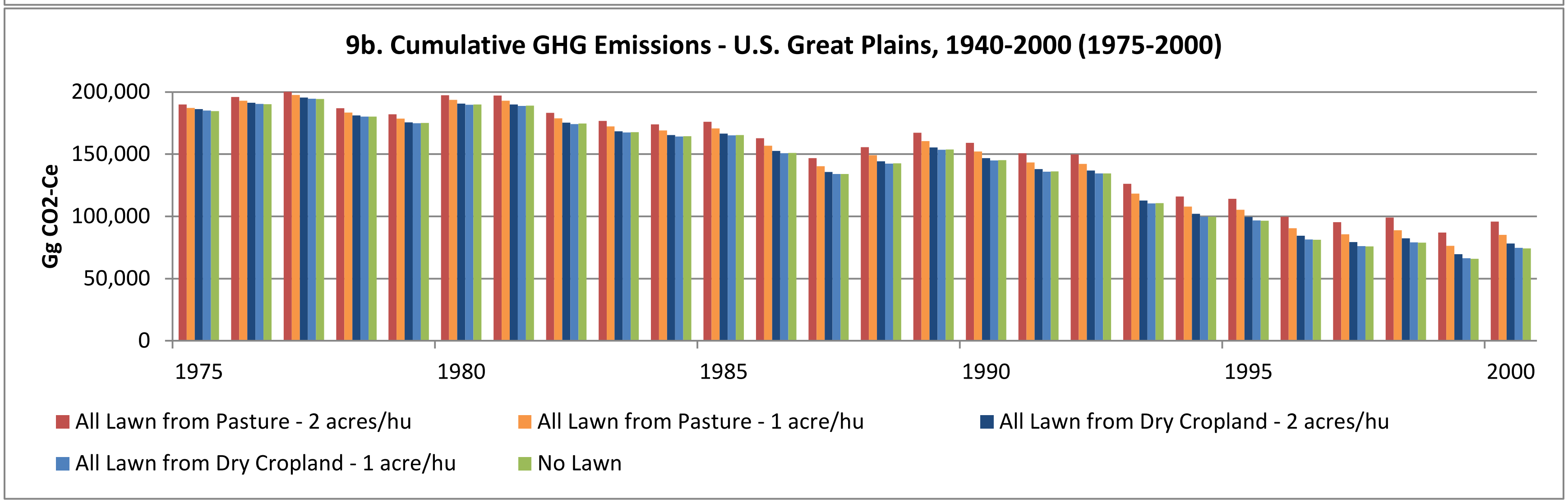


Figure 10. New housing units, U.S. Great Plains, 1940-2000

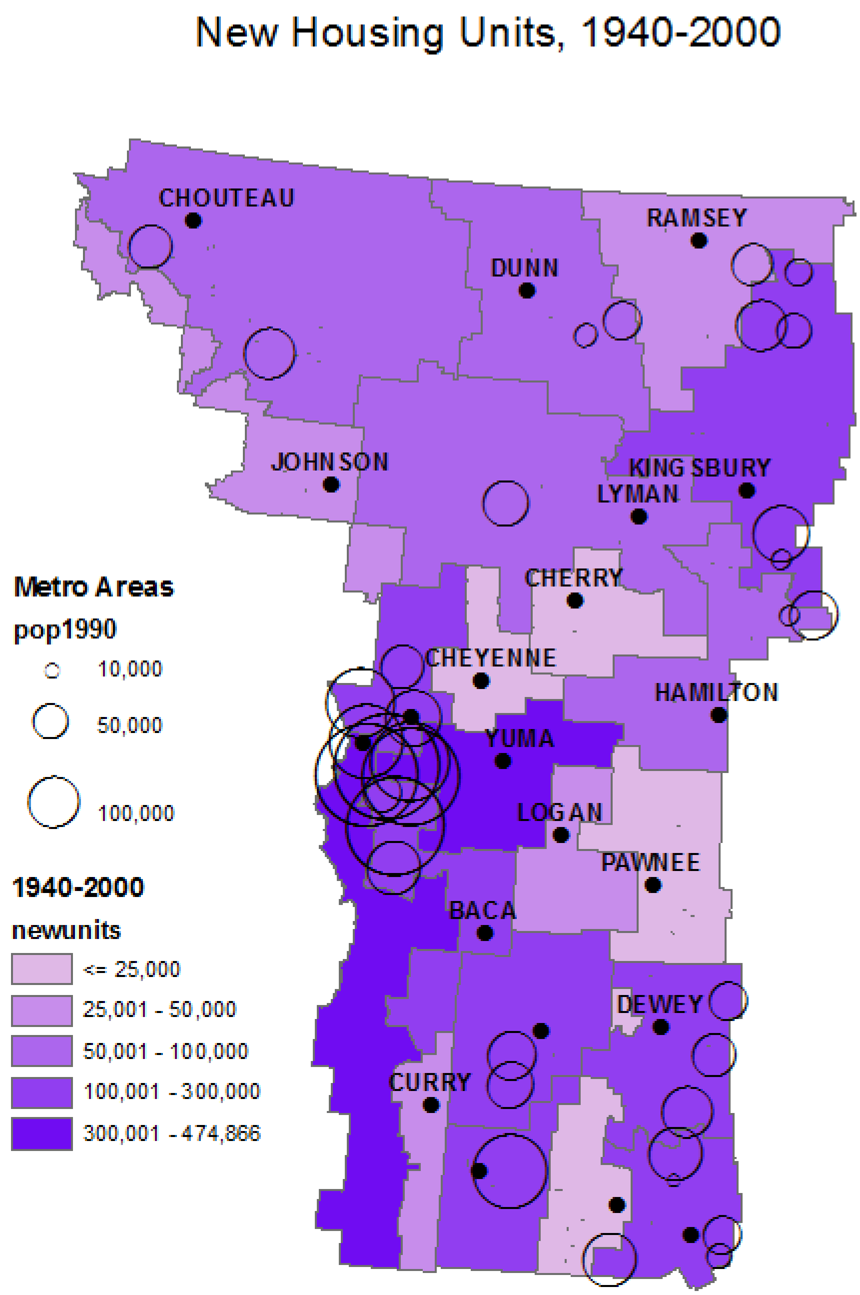


Figure 11. Number of new housing units by 20 year period

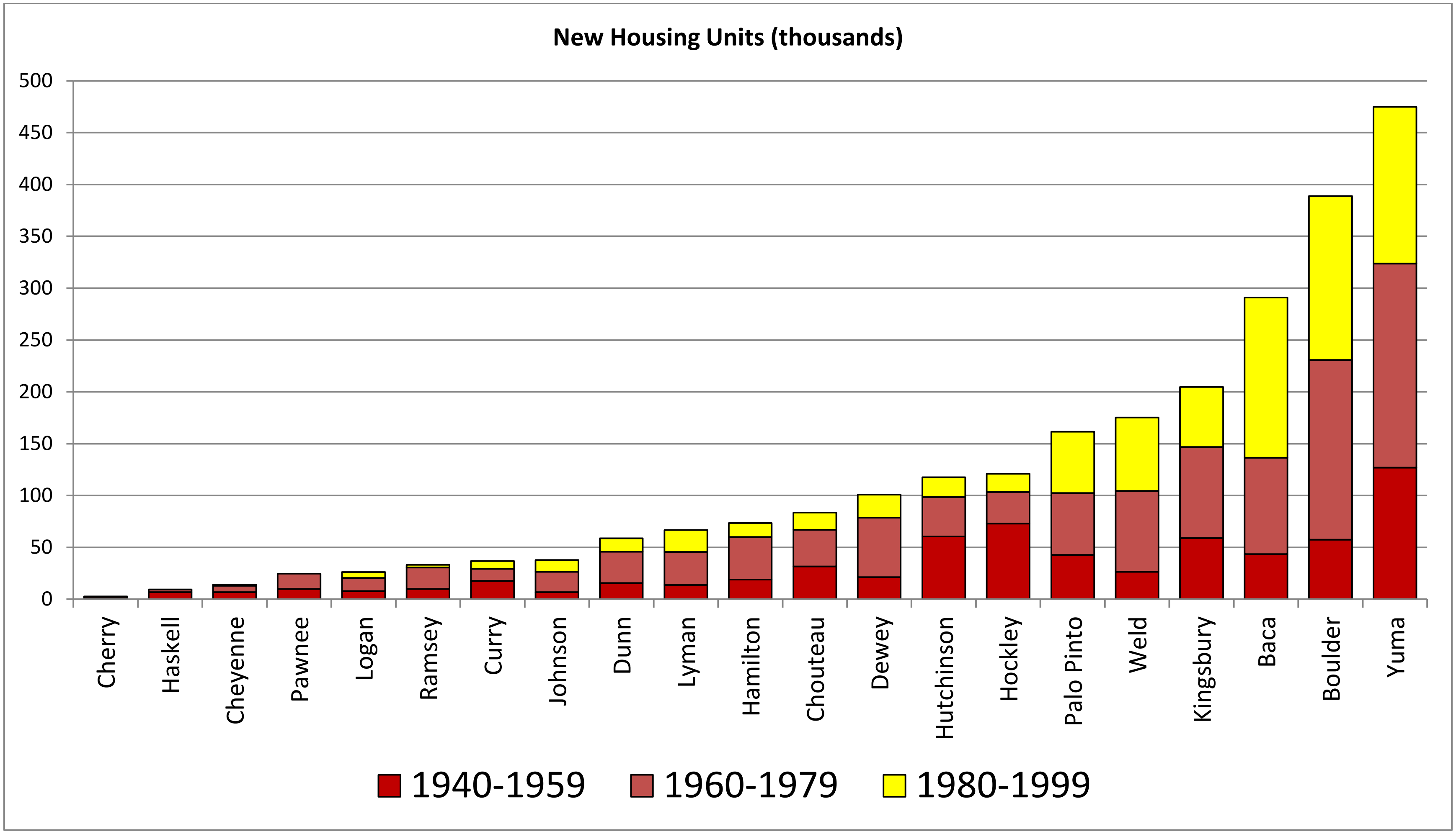


Figure 12. Percent change in cumulative greenhouse gas emissions, 1940-2000, assuming all lawn was previously in pasture

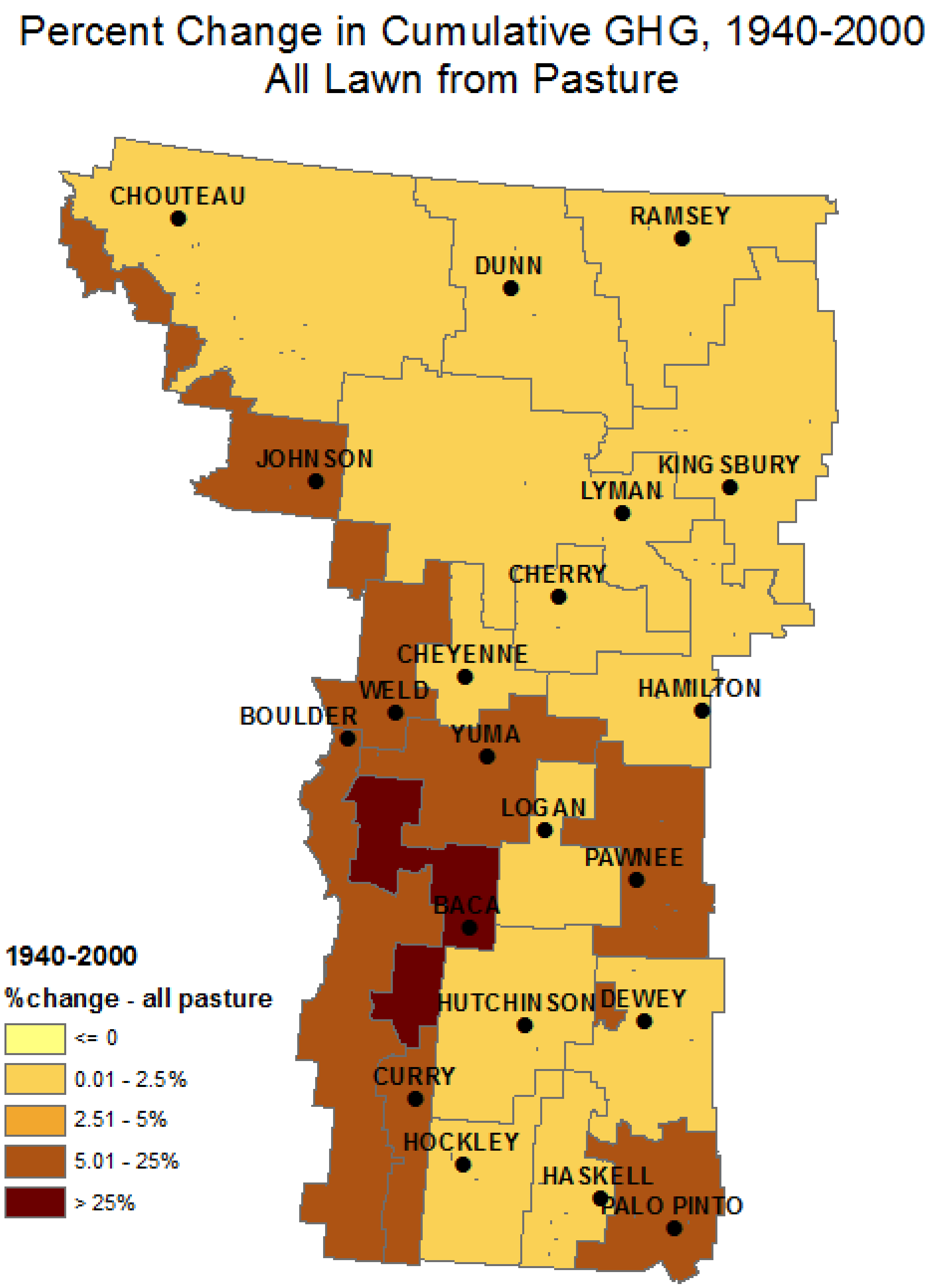


Figure 13. Percent change in cumulative greenhouse gas emissions, 1940-2000, assuming all lawn was previously in dry cropland

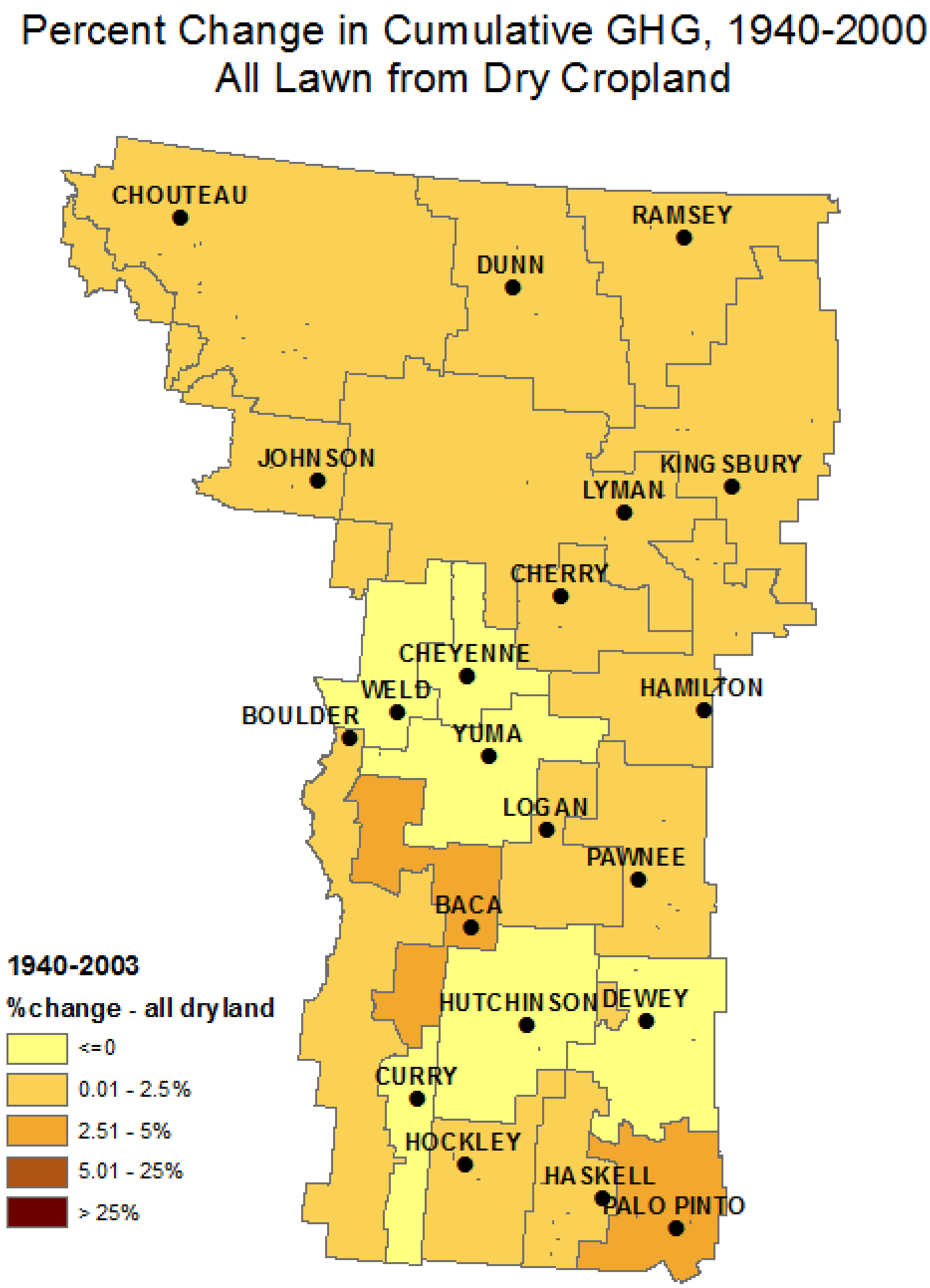


Figure 14. Percent change in cumulative greenhouse gas emissions, 1940-2000, Baca and Boulder, Colorado, assuming 1 acre of lawn per new housing unit

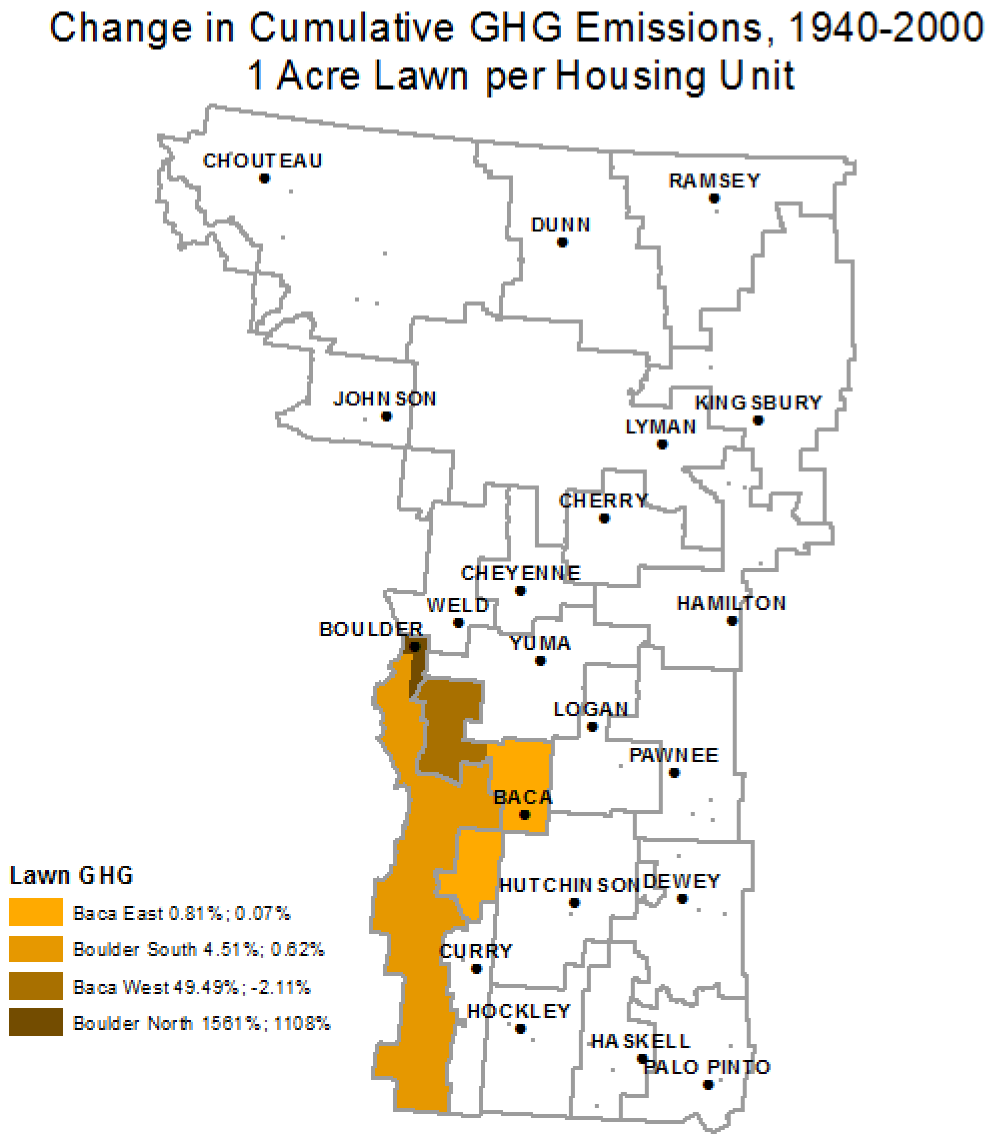


Table 1. Percent change in cumulative greenhouse gas emissions, 1940-2000, assuming all lawn was previously in pasture

Cluster	**1 acre per housing unit**	**2 acres per housing unit**
Baca, CO	30.02%	60.04%
Boulder, CO	22.41%	44.82%
Weld, CO	18.70%	37.41%
Yuma, CO	15.51%	31.02%
Logan, KS	0.37%	0.74%
Pawnee, KS	6.89%	13.79%
Chouteau, MT	0.84%	1.68%
Cherry, NE	0.24%	0.48%
Cheyenne, NE	0.58%	1.16%
Hamilton, NE	1.66%	3.32%
Curry, NM	13.73%	27.46%
Dunn, ND	0.66%	1.31%
Ramsey, ND	2.46%	4.91%
Dewey, OK	2.22%	4.44%
Kingsbury, SD	0.54%	1.07%
Lyman, SD	0.26%	0.53%
Haskell, TX	1.67%	3.33%
Hockley, TX	1.25%	2.50%
Hutchinson, TX	1.33%	2.66%
Palo Pinto, TX	19.48%	38.95%
Johnson, WY	11.31%	22.62%

Table 2. Percent change in cumulative greenhouse gas emissions, 1940-2000, assuming all lawn was previously in dry cropland

Cluster	1 acre per housing unit	2 acres per housing unit
Baca, CO	3.36%	6.72%
Boulder, CO	2.41%	10.53%
Weld, CO	-6.99%	-5.16%
Yuma, CO	-3.95%	7.48%
Logan, KS	0.37%	0.74%
Pawnee, KS	1.65%	3.30%
Chouteau, MT	0.10%	0.20%
Cherry, NE	0.13%	0.25%
Cheyenne, NE	-0.12%	-0.23%
Hamilton, NE	0.35%	0.70%
Curry, NM	-20.84%	-41.68%
Dunn, ND	0.08%	0.15%
Ramsey, ND	0.32%	0.64%
Dewey, OK	-0.31%	-0.61%
Kingsbury, SD	0.42%	0.83%
Lyman, SD	0.30%	0.60%
Haskell, TX	0.02%	0.04%
Hockley, TX	0.06%	0.11%
Hutchinson, TX	-2.01%	-4.01%
Palo Pinto, TX	4.47%	8.94%
Johnson, WY	0.80%	1.61%